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REPORT

DBS PAY TELEVISION:
Picture signal scrambling

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THE BRITISH BROADCASTING CORPORATION

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Summary

Picture signal scrambling methods suitable for a DBS MAC pay television channel are described. They use a technique known as 'rotation scrambling', which is shown to meet the likely requirements for picture quality, security against piracy, scrambling effectiveness and cost (though piracy is discussed in detail in a companion Report.) The methods have been tested using experimental equipment and the results have led to an agreement within the EBU to incorporate them into the MAC specification.

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DBS PAY TELEVISION: PICTURE SIGNAL SCRAMBLING

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1. Introduction

The BBC has investigated a Direct Broadcast by Satellite (DBS) service which could provide television, sound and data channels additional to those on the existing terrestrial network. It was intended that at least one of the television channels would be a subscription or 'pay television' channel. To enforce the subscription, a system of 'conditional access' was envisaged, whereby the broadcast signals would be scrambled, making them unusable unless the viewer has paid for the control information necessary to descramble them. The process by which such information is made available only to paying viewers is known as 'encryption'.

A conditional access television system is secure and effective only if both the picture and sound signals are scrambled. In the envisaged DBS service, the signals are transmitted according to the 'C-MAC/packet' coding standard[1] in which the luminance and colour difference components of the analogue picture signal are time-compressed and -multiplexed and the sound is transmitted in digital form. Scrambling a digital sound signal is a relatively simple matter. Scrambling an analogue picture signal poses more of a problem, despite the fact that MAC decoding in domestic DBS receivers is likely to be implemented digitally.

This Report is about picture signal scrambling, with particular reference to MAC coding. It identifies the requirements for a scrambling method and describes one group of methods, 'rotation scrambling', which fulfil these requirements. Tests on several different rotation scrambling methods, made using experimental equipment in conjunction with a simulated DBS channel, are also described.

2. Picture signal scrambling methods

2.1. Requirements for a scrambling method

Four requirements have been identified which a picture signal scrambling method should fulfil in order to be suitable for pay television:

(i) Quality

There should be no picture impairment attributable to the scrambling and descrambling processes.

(ii) Effectiveness

The scrambling should be effective enough for scrambled pictures to be unwatchable.

(iii) Security

The scrambling should be secure enough for unauthorized descrambling ('piracy') to be more expensive for viewers than the cost of subscribing to the service legitimately. As far as possible, this security should be made 'future-proof'. A distinction needs to be made between this kind of security and the security of the encrypted descrambling control information.

(iv) Cost

The incremental cost of a descrambler in a receiver should be very small, because scrambling and descrambling is performed for the benefit of the broadcaster and does not of itself improve the service to the customer.

2.2. Possible scrambling methods

The possible methods of scrambling a picture signal are numerous. A scrambling process can be performed anywhere in the signal chain from analogue components to final vision signal and can involve transformations in the frequency or time domains.

Considering the four requirements listed above, five possible scrambling methods which could be applied either to PAL or to MAC picture signals were studied in some detail. These were as follows:

(i) Polarity inversion of the picture signal on some lines.

(ii) Stretching and shrinking the video signal in time by varying the clock rate of a shift register through which it passes in sampled form.

(iii) Modulating the line frequency of the video signal.

(iv) Advancing or retarding the picture signal on some lines. This method[2] has been used in France, where it is called Discret 1.

(v) Rotation scrambling, which is described below. One version[3] of this method was devised in France, where it is called Discret 2.

Rotation scrambling was found to be the only one of the five methods that came close to satisfying the requirements listed in Section 2.1 and is therefore the subject of the rest of this Report.

2.3. Rotation scrambling

Rotation scrambling is a time-domain process which is performed separately on each active television line. In the case of MAC signals, it may alternatively be performed on the individual luminance and colour difference components of each line.

Fig. 1 shows the principle of rotation scrambling applied to a PAL signal. A 'cut point' is chosen for each line, the location being given by a pseudorandom binary sequence (p.r.b.s) generator which provides a new cut point number for each line. The line is cut into two segments at the cut point. The two segments are interchanged to form the scrambled line.

The term 'rotation' comes from the following alternative way of thinking of the process: The active line waveform is sampled. The samples are written into a circular shift register. The contents of the shift register are then rotated by an amount which depends on the cut point number. Finally, the scrambled line samples are read out from the shift register. Fig. 2 illustrates the idea.

Descrambling is a reversal of the scrambling process, though it is carried out in a similar way, using a descrambling cut point whose position is

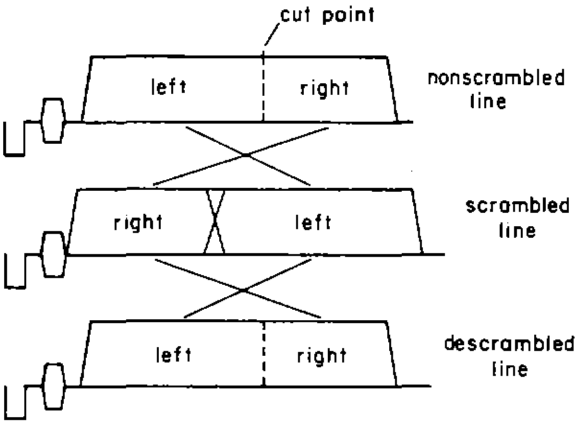


Fig. 1 – The principle of rotation scrambling for PAL signals.

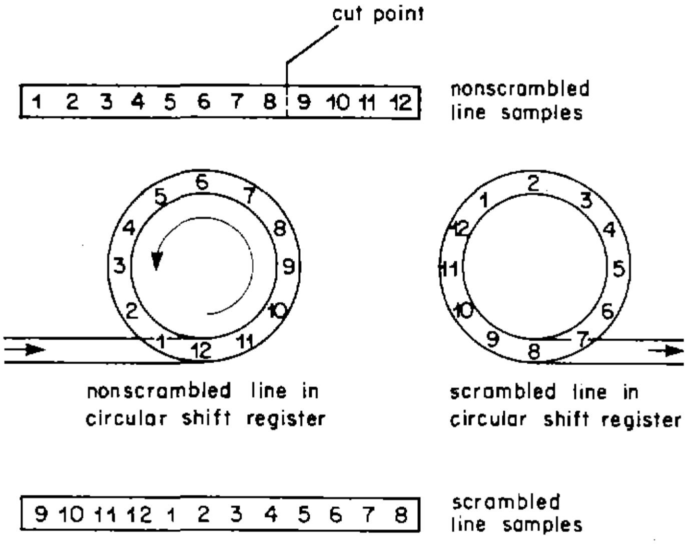


Fig. 2 – Rotation scrambling using a circular shift register.

uniquely related to that of the scrambling cut point.

Section 4 of this Report shows that rotation scrambling for DBS can meet the quality, effectiveness, security and cost requirements listed in Section 2.1.

2.4. Rotation scrambling for PAL signals

Rotation scrambling for PAL signals is known as 'active-line rotation'. An experimental scrambler and descrambler were designed and built, capable of using one of up to 64 different equally spaced cut points for each television line. Initial tests using this equipment showed that with 8 or more possible locations for the cut point on each line the scrambled picture was unrecognizable. Fig. 3 illustrates the effect of scrambling using both 4 and 64 cut point locations.

The descrambled picture was found to be impaired slightly unless special measures were taken to provide 'overlaps' to overcome the problem of signal degradation at the cut point. How this was done is described in Section 3.2.

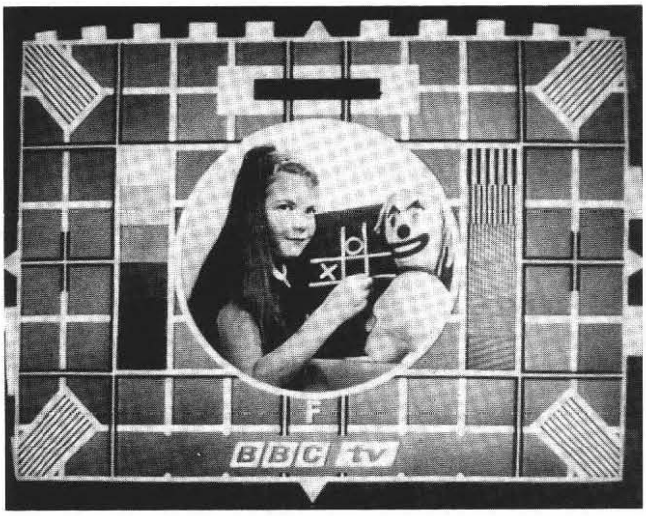
One might think that there would be problems with colour subcarrier phase in the descrambled signal because of slight inaccuracies in the positioning of the descrambling cut point. This is not so, because active-line rotation merely introduces different delays into the two parts of the active line. Provided the lengths of these delays are consistent between scrambler and descrambler, the subcarrier phase will be preserved.

In 1982 the Part committee[4] decided that UK DBS services should use the MAC coding standard rather than the PAL standard as had previously been assumed. It was therefore decided that further studies on scrambling should use MAC signals. The remainder of this Report describes those studies.

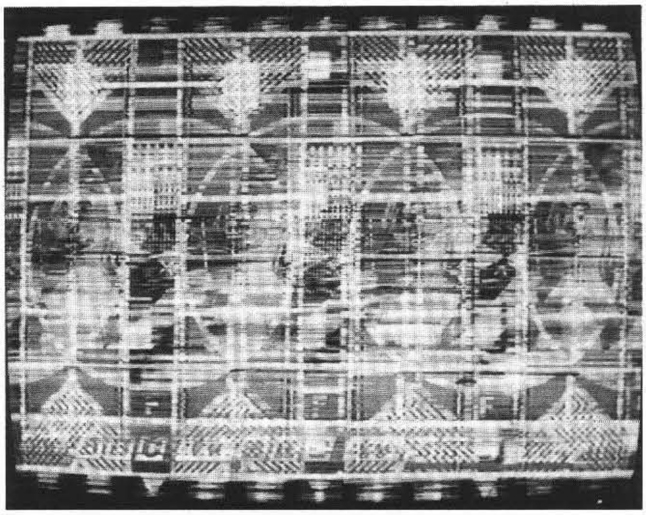
3. Rotation scrambling for MAC signals

3.1. Choices of method

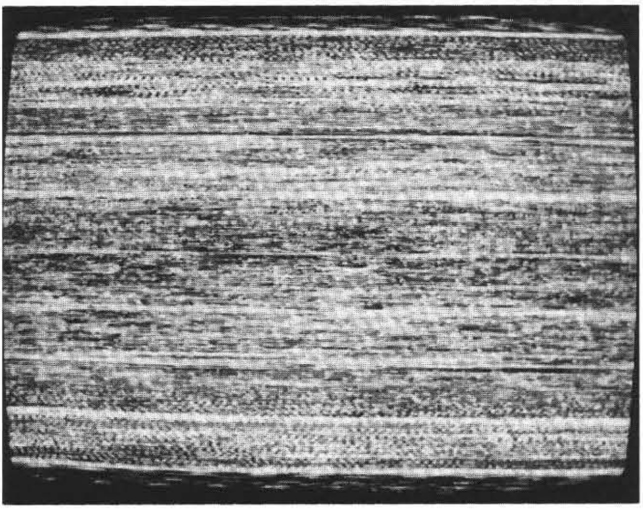
The basic MAC picture signal waveform consists of a 3:1 time-compressed colour difference component followed by a 3:2 time-compressed luminance component. The U and V signals form the colour difference component on alternate lines. Several kinds of rotation scrambling are possible. To describe some of them, the following notation has been devised:



Nonscrambled picture



Scrambled picture - 4 cut points



Scrambled picture - 64 cut points.

Fig. 3 — An example of active-line rotation scrambling using Test Card F.

A point is chosen within the colour difference component, which is then considered to be divided by the point into two segments, C_1 followed by C_2.

Similarly, a point within the luminance component divides it into two segments, L_1 followed by L_2.

The format of a scrambled line can then be described as a permutation of these four segments. To allow the many possibilities to be investigated, a 'universal' MAC scrambler and descrambler were built. They are described in Section 3.3.

3.2. Some problems

As mentioned in Section 2.4, the initial experiments with PAL indicated that the DBS channel and receiver may introduce distortions which would impair the descrambled picture. These distortions include mistiming of the line synchronizing information in the receiver, and ringing in video lowpass filters. It was found that their effect could be greatly reduced by the use of 'overlaps' and of suitably shaped transitions in the scrambled signal.

An overlap allows for inaccuracy in the timing of the descrambling cut point. It is a small portion of the picture signal, around the scrambling cut point, which is transmitted twice. The scrambled active line thus starts a little before the cut point and ends a little after it. This necessitates a very slight increase in the active line duration.

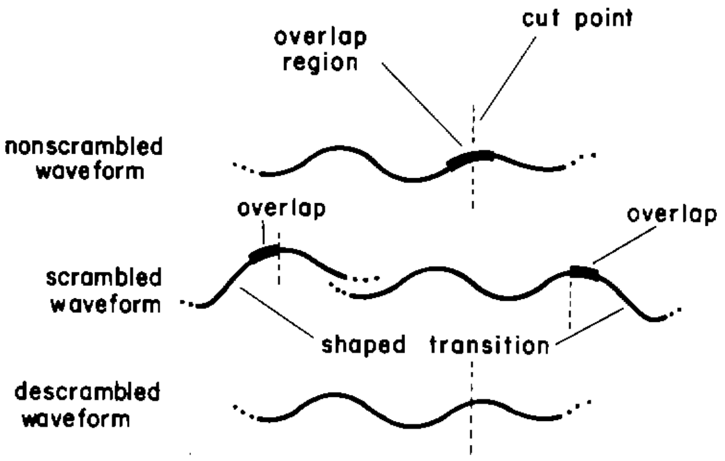


Fig. 4 – The use of overlaps and transition shaping.

Transition shaping ensures that any discontinuity resulting from a cut is shaped so that its spectrum remains well within the bandwidth of the channel, thereby avoiding the effects of ringing which could render the cut points visible on the picture. To achieve this, a small portion of the waveform on each side of the discontinuity is replaced by an interpolated raised-cosine transition.

The two principles are illustrated in Fig. 4. Note that the descrambler simply throws away the overlaps and the shaped transitions. The universal scrambler and descrambler described below allowed various overlap lengths and transition shaping schemes to be tried out.

3.3. Experimental equipment

The experimental equipment consisted of a scrambling RGB-to-MAC coder and a descrambling MAC-to-RGB decoder. It was based on a MAC codec designed specifically for this investigation. The MAC coding was implemented digitally at the MAC sampling rate of 20.25 MHz. The scrambling process was performed at the same time and was controlled by data held in a programmable read-only memory. Similar remarks apply to the decoder and descrambler. Computer programs were developed to generate data for the control memory from information about the scrambling method being tested.

Picture signal synchronizing information was conveyed to the decoder by introducing special baseband synchronizing pulses into the line blanking period. This was necessary because no C-type sound/data signal was available when the experiments were being performed. The equipment therefore provided a baseband MAC video signal.

The design of the equipment is described in detail in Appendix 1.

3.4. Scrambling methods implemented on the equipment

Three scrambling methods were implemented. For each method, the number of possible cut points available for each line could be varied up to the specified maximum.

(i) Double-cut component rotation. This is $C_2 C_1 L_2 L_1$ in the notation given in Section 3.1. The colour difference and luminance components are treated separately. Two 8-bit cut point numbers are required for each line. One of these determines the cut point location for the colour difference component; the two segments C_1 and C_2 so obtained are interchanged before transmission. The other cut point number is for the luminance component, which is treated in the same way. Fig. 5 illustrates this method.

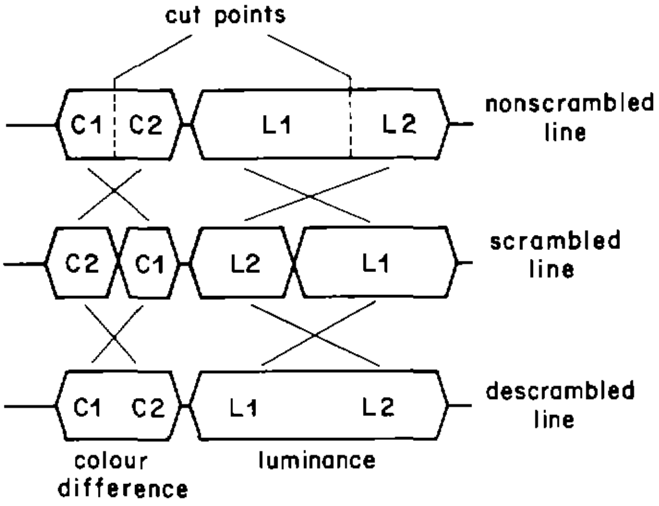


Fig. 5 – Double-cut component rotation scrambling.

The experimental equipment uses a maximum of 8 bits for the cut point numbers on each line, so for simplicity the luminance and colour difference cut point numbers were constrained to be equal. This is an acceptable constraint for testing purposes because it can only reduce the quality of the descrambled picture.

(ii) Single-cut line rotation ($C_2 L_1 L_2 C_1$). In this method, the active line is treated as a whole, rather like active-line rotation described in Section 2.4. Here, however, an 8-bit cut point number specifies a cut point within the period of the colour difference component. The method is illustrated in Fig. 6.

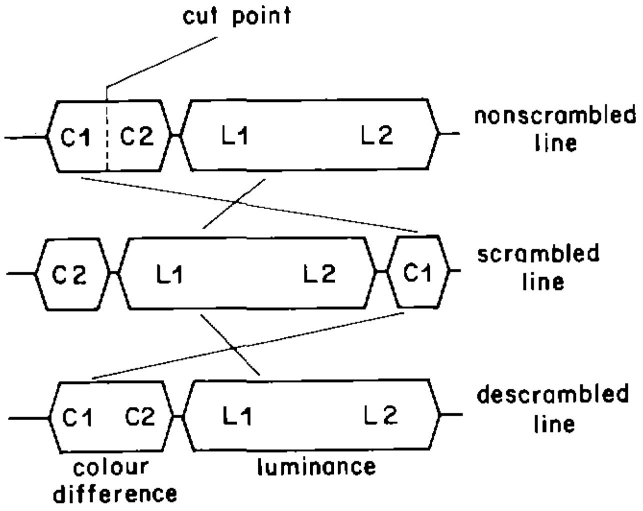


Fig. 6 – Single-cut line rotation scrambling.

(iii) Component permutation ($L_1 L_2 C_1 C_2$ or $C_1 C_2 L_1 L_2$). This method, shown in Fig. 7, needs only a 1-bit cut point number. According to its value, the line is either left as it is or the two components are interchanged. The only cut point is between the two components, so there is no need for overlaps or for shaped transitions.

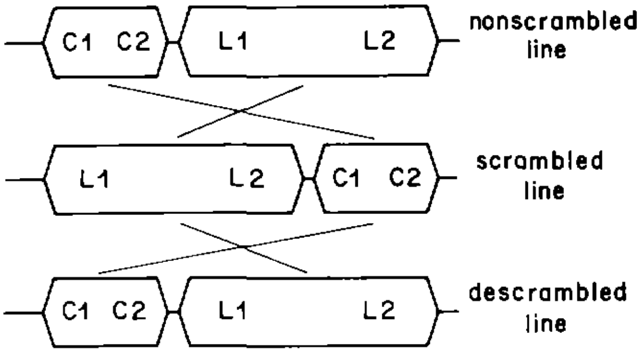


Fig. 7 – Component permutation scrambling (shown for the case when the cut point number specifies that the components are to be interchanged).

4. Performance of MAC rotation scrambling

This Section examines how well MAC rotation scrambling meets the four requirements listed in Section 2.1. The main part of the Section is concerned with tests which were carried out during and after an EBU meeting* in August 1983 on the quality of descrambled signals. The remainder of the Section deals with the requirements for effectiveness, security and cost.

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* Meeting of EBU Working Party V Ad-hoc Group on Conditional Access.

4.1. Tests on the quality of descrambled signals

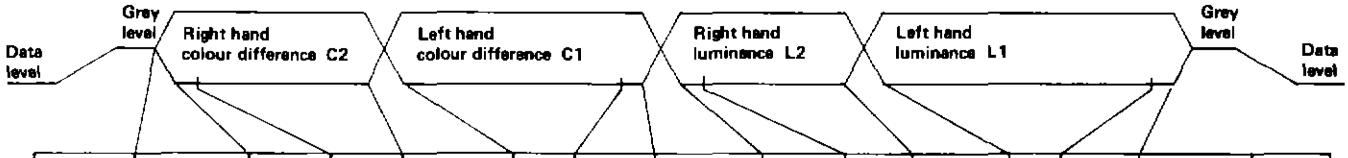
The most extensive tests were carried out on double-cut component rotation scrambling. They are described in Sections 4.1.1 to 4.1.5. The other two scrambling methods are discussed in Section 4.1.6.

No satellite channel was available for the tests, so a simulator[5] was used. The simulator produced a frequency modulated signal on a 70 MHz carrier and performed the associated demodulation. A number of distortions could be introduced into the simulated channel, between the scrambler and the descrambler. These distortions were used in conjunction with suitable test signals to assess the effect of scrambling and descrambling on picture quality.

One requirement of the tests was to determine the optimum specification for overlaps and for shaped transitions. After considering the various possibilities, eight different scrambling schemes, having various combinations of overlap and shaped transition lengths, were chosen. These were implemented using the equipment and are summarized in Table 1. In each scheme, the overlap length is the number of samples by which the scrambled luminance or colour difference component was extended beyond the cut point. The length of a shaped transition includes the start and finish samples, between which a raised-cosine interpolation was made.

TABLE 1

The eight scrambling schemes tested, showing the number of samples assigned to each period identified.



Scrambling scheme	Transition grey to C2	Overlap C2	C2	Transition C2 to C1	C1	Overlap C1	Transition C1 to L2	Overlap L2	L2	Transition L2 to L1	L1	Overlap L1	Transition L1 to grey	Spare samples
A	5	1	347-r	3	r	1	5	1	697-2r	3	2r	1	5	0
B	3	2	347-r	3	r	2	5	2	697-2r	3	2r	2	3	0
C	4	2	347-r	3	r	1	5	2	697-2r	3	2r	1	4	0
D	5	0	347-r	5	r	0	5	0	697-2r	5	2r	0	5	0
E	3	1	350-r	3	r	1	3	1	700-2r	3	2r	1	3	0
F	3	3	347-r	3	r	3	0	3	697-2r	3	2r	3	3	1
G	5	1	350-r	0	r	1	5	1	700-2r	0	2r	1	5	0
H	3	1	353-r	0	r	1	3	1	703-2r	0	2r	1	3	0

(The number r is determined by the cut point number)

A number of possible causes of picture impairment were examined, as described below. The work was concerned primarily with the impairments likely to be suffered by scrambled DBS pictures. However, there is a possibility that scrambled MAC picture signals will be used in cable systems and in terrestrial television broadcasting. There were early indications that special problems might exist in these cases, which were therefore borne in mind when the work was carried out.

In all the tests, the minimum acceptable picture quality was that corresponding to 'Just Perceptible' impairment. EBU test pictures such as 'Boats' and 'Formal Pond', as well as Test Card F, were used in most of the tests.

4.1.1. Inaccurate recovery of line synchronism in the decoder

This was achieved by mistiming the line synchronizing pulse in the decoder by up to 200 ns. It is thought that timing errors in domestic DBS receivers will be well below 60 ns. Two kinds of effect on the descrambled picture were studied: visibility of cut points due to ringing or to gross mistiming, and crosstalk between the left and right edges of the picture (because these are juxtaposed in the scrambled signal).

In addition to EBU test slides, some special critical test signals were devised. These consisted of large, slowly moving patterns formed from various combinations of the R, G and B source signals. They appeared as wide vertical coloured or grey bars moving slowly across the screen. Another technique that was used to make critical comparisons between the eight schemes was to constrain the cut point number to be the same on each line, so that any impairment due to the rotation processes now appeared as a thin stationary vertical line, rather than an apparently random scattering of small dots over the picture.

It was only by using these particularly sensitive techniques that any difference could be discerned between the eight scrambling schemes. It was found that one sample for each overlap was necessary and sufficient to make cut points invisible for timing errors of up to 60 ns in either direction. Transitions containing three samples were found to be sufficiently long to remove impairments due to 'ringing'. With three-sample transitions between the two parts of each component, the effect of left-right crosstalk could be seen at the extreme edges of the picture, with 60 ns timing errors and the most critical test material. However, the receiver would be expected to discard the extreme left hand and right hand samples of the descrambled waveform; the crosstalk effect would then be imperceptible.

Considering these results, Scheme E, which has overlaps of one sample and transitions of three samples, was chosen as the most acceptable. This scheme, with some trivial variations, has since been accepted as the EBU standard for double-cut component rotation scrambling[1].

4.1.2. Simulated rf satellite link distortions

The simulated satellite link included a distorting unit[5] to simulate worst-case up-link, down-link and transponder distortions. The introduction of these distortions produced no subjective effect which could be attributed to scrambling or to descrambling. Even with gross distortions the effect of scrambling and descrambling was slight.

The effect of channel noise was also simulated. Here, the scrambling and descrambling processes did produce visible impairments at very low carrier-to-noise ratios, but they were negligible compared with the effect of noise on a nonscrambled signal and did not affect the overall subjective quality of the picture.

4.1.3. Line tilt

Line tilt is an effect which can be caused either by the addition of small unwanted line-sawtooth components, such as might occur in a clamping circuit, or by a nonuniformity in the amplitude/frequency response of the channel at low video frequencies. A problem of the latter kind is more likely to be encountered in the vsb/am circuits of terrestrial or cable television networks than in a DBS fm channel.

Picture signals that have been scrambled and descrambled by a rotation process are very much more susceptible to line tilt impairment than nonscrambled signals. The impairment is seen as coarse streaky noise on the descrambled picture.

Line tilt was introduced for test purposes by adding a low-level line-frequency sawtooth signal to the scrambled MAC picture signal. The extent of the line tilt is defined as the ratio of the sawtooth excursion to the peak-to-peak picture signal level, expressed as a percentage. Various values of line tilt up to 3% were used. Tests with the most critical material showed that 0.3% was an acceptable maximum. Values greater than 0.3% produced perceptible 'streaky noise' effects on the descrambled picture.

4.1.4. Multipath distortion

An echo was added to the modulated rf signal with a delay set to 0.2, 0.3, 0.6 or 1.7 microseconds. For each delay value the level of the echo was set to a value of up to twice the maximum recommended for a cable distribution system[6]. Such maximum echo levels are, of course, much greater than would be encountered in a DBS channel. Impairments attributable to scrambling or descrambling could be seen only with the highest levels of echo. However, with such levels the effects were insignificant when compared with the ghosting effects caused by the echo on a nonscrambled signal.

4.1.5. Co- and adjacent-channel interference

An interfering signal was introduced to either the upper or the lower adjacent satellite channel, or into a channel of the same frequency as the wanted signal. The interfering signal was not scrambled. Tests were carried out with Test Card F or colour bars as the wanted picture and colour bars or Test Card F respectively as the interfering picture.

It was observed that scrambling reduces the effect of co- and adjacent-channel interference. The improvement was found to be substantially independent of the choice of test picture, but was generally small, reducing the acceptable interference ratio by up to 2 dB.

4.1.6. Other rotation scrambling methods

The above results for double-cut component rotation scrambling show that, while the method would be suitable for DBS, it would probably not be suitable for terrestrial or cable distribution of MAC signals using existing networks. This is because such networks would not necessarily satisfy the required tolerance for line tilt.

This problem led to proposals from the Independent Broadcasting Authority for the single-cut line rotation and component permutation methods described in Section 3.4. The BBC and some other EBU members carried out limited tests on these methods. The tests showed[1] that single-cut line rotation scrambling is less sensitive than the double-cut method to the poor amplitude/frequency response of vsb/am channels at low frequencies, except in the case of highly saturated colour pictures, when it is somewhat more sensitive. There was also evidence from some of the tests that all three forms of rotation scrambling may aggravate the effects of over-modulation in a vsb/am channel.

Component permutation also showed some impairment due to vsb/am channel response, but this is of no consequence because the method was abandoned by all members of the EBU because of its extreme vulnerability to piracy.

4.2. Effectiveness of MAC rotation scrambling

A brief look at the scrambled picture reveals that, with more than about eight possible cut points, single- and double-cut rotation scrambled pictures look similar to scrambled PAL pictures and are unrecognizable in their scrambled form. The requirement for effectiveness is therefore met. Component permutation is not quite so effective but the scrambled picture can be regarded as unwatchable.

4.3. Security against piracy

To complete the investigation of the three rotation scrambling methods, a study of their relative security was made. The study was based on an investigation, using computer simulation on still pictures stored in digital form, of algorithms which attempt to descramble a scrambled picture using knowledge of picture statistics alone. The following is a brief summary of the results:

(i) None of the three rotation scrambling methods is completely secure against piracy. The algorithms tested enabled most pictures to be descrambled sufficiently well to be recognizable.

(ii) None of the methods can be pirated with complete success. In other words, for any known piracy algorithm there are pictures which it will fail to reconstruct perfectly. However, for component permutation scrambling there are simple algorithms which will reconstruct nearly all pictures perfectly.

(iii) Single-cut rotation is much less secure than double-cut rotation. Piracy algorithms for double-cut rotation rely almost exclusively on inter-line correlation techniques in which several lines of storage are required and in which the effect of errors is cumulative. Algorithms for single-cut rotation can make additional use of the fact that the whole structure of each line is changed by scrambling in a way which depends on the cut point, so that simpler and cheaper intra-line techniques involving the relative probability distributions of colour difference and luminance signal levels can be used. These can be made more reliable because errors are limited in their effect to the line in which they occur.

(iv) The security of single- and of double-cut scrambling is severely reduced if the number of possible cut points for each line is reduced.

(v) A piracy algorithm for double-cut scrambling which provides watchable pictures sufficiently reliably would be very complex, probably requiring a video frame store and high-speed processing. It would cost more than several years' DBS subscription and would probably continue to do so for many years to come.

It can be concluded from these results that double-cut scrambling is sufficiently secure; it is thought to be as secure as any known scrambling method which meets the other requirements of pay television.

4.4 Receiver cost

The design of the experimental equipment indicated that rotation descrambling can be implemented in domestic receivers at the same time as MAC decoding and that very little, if any, additional memory is required. The incremental cost of a descrambler is therefore likely to be negligible.

5. Conclusions

A scrambling method for MAC picture signals, known as 'double-cut component rotation', has been designed and implemented. The method was tested in conjunction with a simulated direct broadcast satellite link and was shown to be suitable for a DBS pay television service. However, doubts remain about its suitability for vsb/am terrestrial or cable networks. An investigation into possibilities of piracy has shown that it is a very secure scrambling method.

6. References

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Appendix

Description of experimental equipment

The coder requires a standard feed of analogue baseband RGB and "mixed syncs" signals. Its output is a baseband MAC signal whose format is very similar to that given in the C-MAC specification[1], with the exception of the baseband synchronizing pulses described below. The decoder accepts the baseband MAC signal and produces RGB and "mixed syncs" output signals. The decoder also provides access to its internal synchronizing circuits in the form of an output and input between which a delay can be introduced. This is useful for experiments such as observing the effects of inaccurate line synchronization, as described in Section 4.1.1.

A1.1. Coder and scrambler

A block diagram of the coder and scrambler is given in Fig. A1.

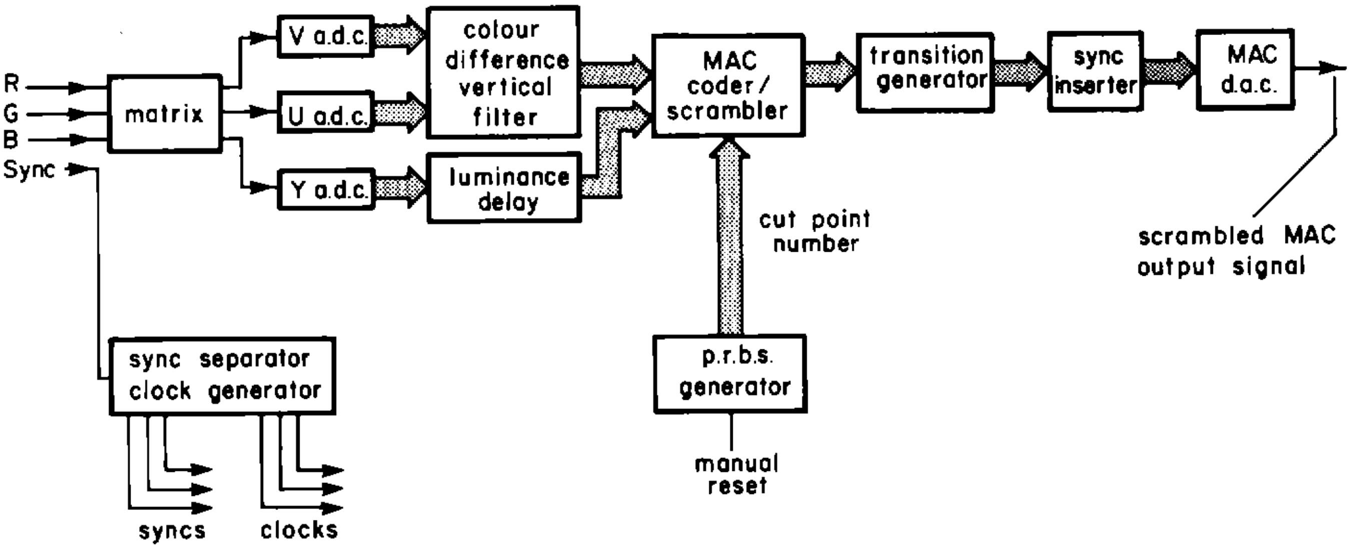

Fig. A1 – Block diagram of MAC coder and scrambler.

The RGB-to-YUV matrixing is carried out on the analogue signal components. The colour signal equations are given in the C-MAC specification. Note, however, that the U and V signals are not limited to 77 per cent saturation as described in the specification.

The matrixed Y signal is lowpass filtered to a bandwidth of 5.6 MHz, clamped, sampled at 13.5 MHz and quantized to 8-bit accuracy so that black is level 64 and white is level 255. The matrixed U and V signals are separately lowpass filtered to a bandwidth of 2.8 MHz, clamped, sampled at 6.75 MHz and quantized to 8-bit accuracy so that grey (zero colour difference) is level 128 and the positive and negative peaks of the colour difference signal are at levels 223 and 32 respectively.

Vertical pre-filtering is then applied to the digital U and V signals and the filter circuit provides a single output of alternate lines of U and V. The vertical filtering process delays the colour difference signal by one line period each in both the coder and the decoder. To compensate for this, the luminance signal is delayed by two line periods in the coder.

The incoming synchronizing pulses are separated into their line and field components in order to provide synchronizing information and clock pulses for the rest of the coder.

The cut point number is generated by a p.r.b.s. generator. For the purpose of experiment, there was no need for this generator to be secure, as it would be in a real encryption system, so a 31-element linear feedback shift register is used. The p.r.b.s generator is reset by loading all the elements with '1'; this is controlled manually. In addition, eight switches are provided so that each of the eight bits output from the p.r.b.s generator can be forced to '0' or to '1' if desired.

The MAC coder/scrambler circuit is based around two read/write stores, each of which contains one line's worth of MAC samples. While one store is being written, the other is being read.

The MAC coding is carried out by writing luminance and colour difference samples into the store as they arrive, under the control of a write address generator which consists of a PROM fed by a sample counter. The store then contains the samples of a nonscrambled MAC line. It follows that the specification (e.g. length of active line) can be changed by reprogramming the write address PROM.

The scrambling is done by reading the samples from the store under the control of a read address generator. This consists of a sample counter which can count through up to 8 increasing sequences of consecutive numbers. The start and finish of each sequence is stored in a PROM whose inputs are as follows:

3 bits giving the 'scheme number' which is selected manually so that up to 8 different scrambling schemes can be compared quickly;

3 bits according to which of the 8 sequences currently forms the output from the read address generator;

8 bits giving the cut point number.

Hence, the positions, lengths and order of up to eight segments of the MAC line can be made to depend upon the cut point number. This enables any of the component rotation or line rotation methods which have been suggested, including different overlap schemes, to be tried out.

Transition shaping is implemented by replacing the samples in each chosen transition period with interpolated samples. These are calculated from raised cosine (or similar) shapes stored in a set of PROMs, which are added to or subtracted from the sample values at either end of the transition period. Another set of PROMs contains information which defines how long each shaped transition should be.

The sync inserter generates baseband synchronizing pulses to carry line, picture and p.r.b.s synchronizing information. An interval with a duration of 192 MAC clock periods between the line synchronizing reference and the start of the active line is used to form the pulses. The period is divided into four slots, each 48 samples long. For the first two slots the signal is set to level 0. This provides a line synchronizing pulse very similar to that of a PAL signal. For the third slot, the signal is set to level 128 except on line 1 (once per picture) when it is set to level 0. This has the effect of lengthening the line synchronizing pulse to provide picture synchronization. The fourth slot is used to synchronize the p.r.b.s generator controlling the descrambler with an identical p.r.b.s generator at the scrambler. The signal is set to level 128 except when both p.r.b.s generators are to be reset, when it is set to level 0. The pulses created by this process are filtered to give them a rise time of about 225 ns.

The MAC digital-to-analogue converter includes lowpass filtering and (sin x)/x equalization appropriate to a sampling frequency of 20.25 MHz.

A1.2. Decoder

A block diagram of the decoder and descrambler is given in Fig. A2 (shown overleaf). In general, the operation of the decoder and descrambler is a straight reversal of that of the coder and scrambler.

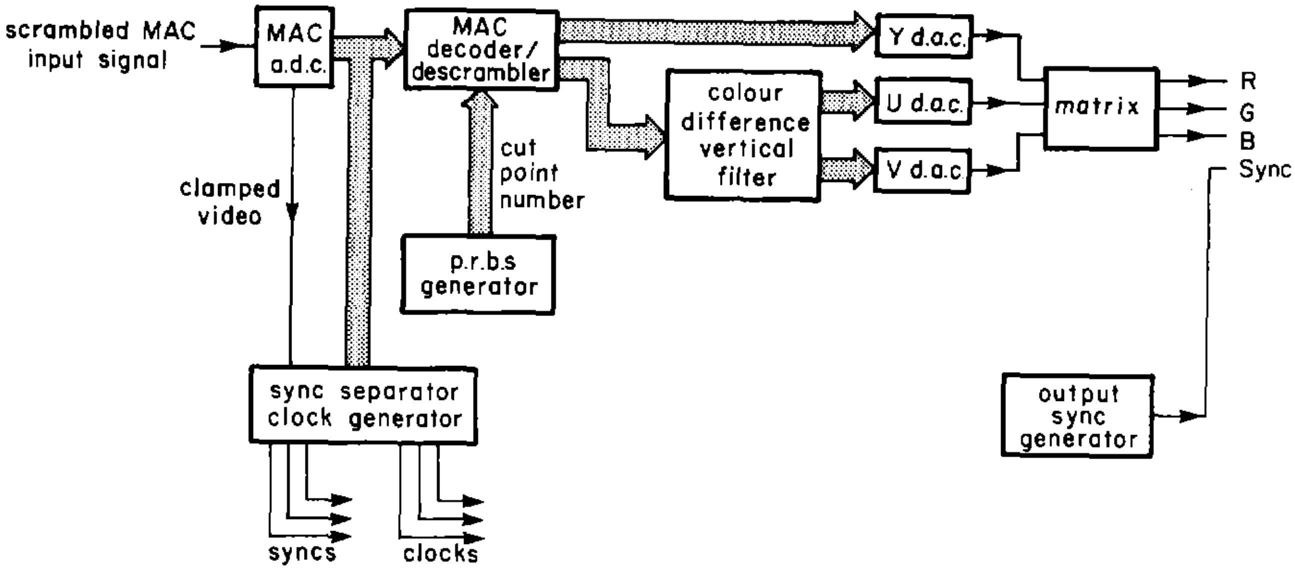

Fig. A2 – Block diagram of MAC decoder and descrambler.

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